ASSESSING THE ECONOMIC BENEFITS OF GROUND WATER FOR ENVIRONMENTAL POLICY DECISIONS'

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DISCLAIMER

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I. INTRODUCTION

The full range of environmental and economic services of ground water need to be accounted for in policy decisions. Nonrecognition of these services imputes a lower value for the ground water resource in establishing policies. One outcome, not evaluated in this paper, is that the allocation of public and private funds to prevent contamination is skewed toward other water and environment resources. As the function of ground water in the hydrologic cycle and ecosystem are better understood, funding decisions to prevent adverse effects to the resource will more fully recognize ground water's role. In particular, in EPA Comprehensive State Ground Water Protection Programs, States are to consider the value (as well as the vulnerability) of the ground water resource in establishing policies for preventing and remediating contamination across all ground water-related programs (U.S. EPA, 1993b). This paper presents steps to assess the services of ground water more fully in environmnetal decisions.

In the next section of this paper, we describe a conceptual framework for identifying and measuring the economic value of ground water. The valuation framework links changes in physical characteristics of ground water to uses (services) provided by ground water and the economic effects of changes in ground water services. This framework provides a means for guiding the estimation of ground water values across different studies so as to generate valid, consistently measured values with minimum duplication of scarce time and effort available for policy assessment. Following this section, we discuss the application of economic values to ground water policy decisions. We present summary observations and conclusions in the final section.

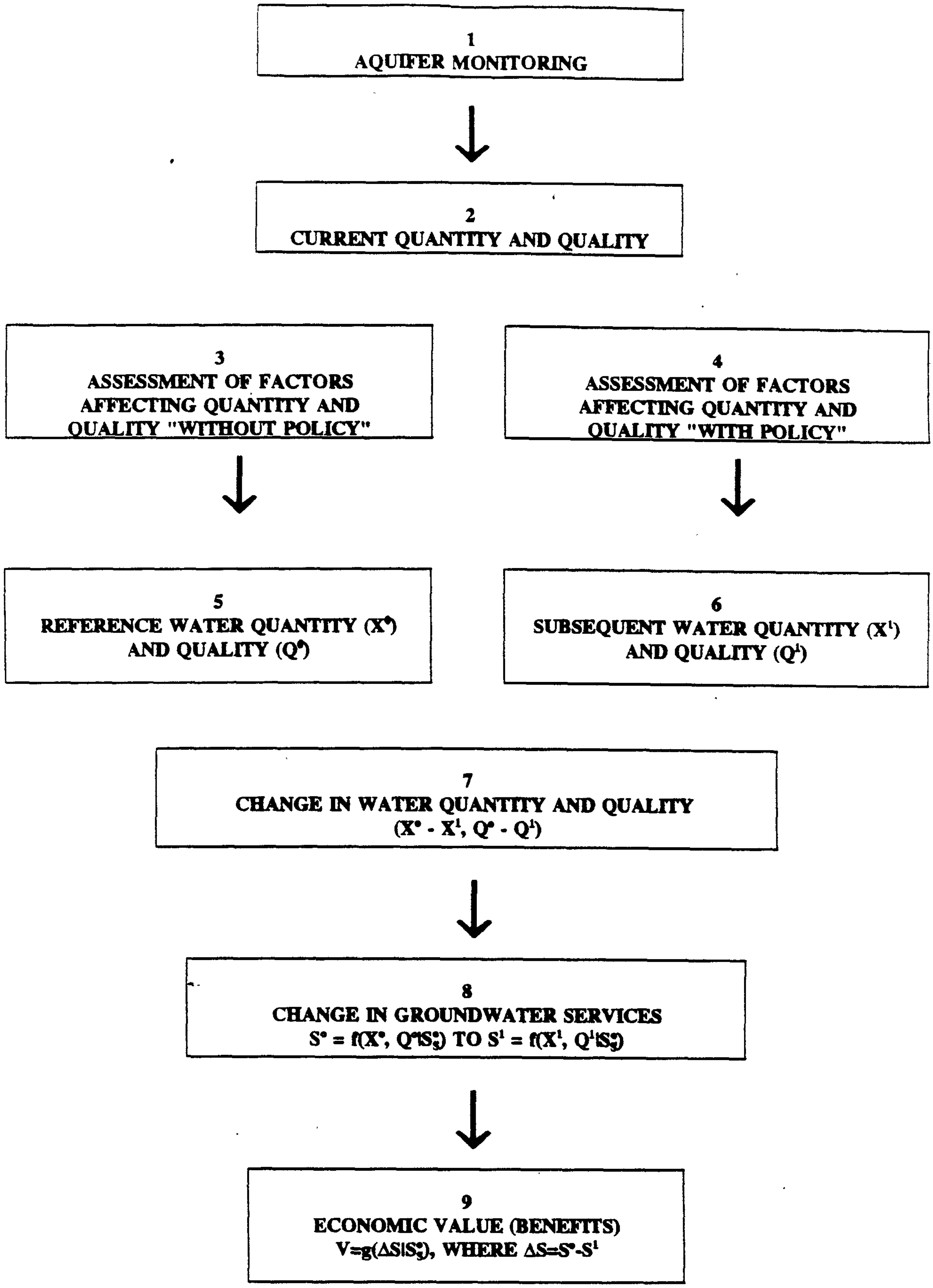
II. FRAMEWORK FOR VALUING GROUND WATER

A fundamental issue involved in valuing any environmental resource is defining the change in the condition of a resource and the ensuing changes in services generated by the resource, i.e., commodity definition. This begins with an understanding of whether the change has occurred or is proposed. Given ex post or ex ante standing, the next step is to develop a technical definition of the reference condition of the resource and identify whether the increment of change is an enhancement or diminishment of the quantity and quality of the resource. For either enhancing or protecting ground water, the expected condition of the resource. must be defined. Differences between the reference condition and expected condition define the change in the quantity and quality of a resource to be evaluated. Consideration should also be given to whether or not the mechanism(s) employed to accomplish the change can achieve the proposed resource condition with certainty. It is also necessary to know the geographical extent of the changes because the resultant economic values are spatially dependent. Finally, it is important to establish a relationship between the physical change in the ground water resource and changes in the provision of services from which humans derive value. This information collectively constitutes the formal commodity definition for a resource being valued.

Defining Ground Water Values

Valuing ground water requires a clear definition of the ground water “commodity” to be valued. Figure 1 summarizes the technical data required to define a ground water commodity. The first step is monitoring (Box 1) to assess the current or baseline aquifer condition in quantity and quality dimensions (Box 2). The next step is to assess how the current quantity and quality of ground water will change "with" and "without" the proposed regulation (Boxes 3 and 4). These factors include extraction rates, natural recharge and discharge, natural contamination (e.g., salt infiltration) and human-induced contamination (e.g., pesticide contamination, industrial chemical contamination), and public policies regarding the use and protection of ground water. The results of the assessments provide estimates of the reference (without policy) water quantity (X^0) and quality (Q^0), and the subsequent (with policy) water quantity (X^1) and quality (Q^1) (Boxes 5 and 6). Given estimates of the reference and subsequent ground water conditions, we define the change in water quantity and quality $(X^0 - X^1, Q^0 - Q^1)$ (Box 7). The steps and linkages illustrated by Boxes 1-7 primarily involve the work of hydrologists, geologists, engineers, ecologists, soil scientists, and other physical and biological scientists. However, investigations of ground water conditions by these specialists must be sufficient to identify changes in ground water services linked to the prescribed policy in a manner that facilitates the estimation of economic values. Formally modeling the steps illustrated by Boxes 1-7 represents one of the greatest challenges that needs to be addressed to estimate economic values of ground water protection.

FIGURE 1


1
AQUIFER MONITORING
2
CURRENT QUANTITY AND QUALITY
3
ASSESSMENT OF FACTORS AFFECTING QUANTITY AND QUALITY "WITHOUT POLICY"
4
ASSESSMENT OF FACTORS AFFECTING QUANTITY AND QUALITY "WITH POLICY"
5
REFERENCE WATER QUANTITY (X^0) AND QUALITY (Q^0)
6
SUBSEQUENT WATER QUANTITY (X^1) AND QUALITY (Q^1)
7
CHANGE IN WATER QUANTITY AND QUALITY
($X^0 - X^1$, $Q^0 - Q^1$)
8
CHANGE IN GROUNDWATER SERVICES
$S^0 = f(X^0, Q^0|S_0^*)$ TO $S^1 = f(X^1, Q^1|S_0^*)$
9
ECONOMIC VALUE (BENEFITS)
$V=g(\Delta S|S_0^*)$, WHERE $\Delta S=S^0-S^1$

Reference services (S^o) supported by ground water are determined by the without policy ground water quantity (X^o) and quality (Q^o) and subsequent services (S^1) are determined by the with policy ground water quantity (X^1) and quality (Q^1). Reference and subsequent ground water services are conditional upon given levels of substitute and complementary service, flows (S_s^0) (Box 8). The interactions of scientists and policy analysts facilitate the mapping of changes in the condition of ground water to changes in service flows which affect economic activities. We can then estimate economic value (e.g., willingness-to-pay) as a function of the change in the ground water service flows, given the specified reference and subsequent ground water conditions, and service flows from substitutes and complements to the ground water resource (Box 9). Economic valuation of ground water therefore requires that progress be made on two fronts: establishing formal linkages between ground water protection policies and changes in the biophysical condition of ground water (Boxes 1-7), and developing these linkages in a manner that allows for the estimation of policy-relevant economic values (Boxes 8-9). Ideally, steps 1 through 9 involve interactions and cooperation between economists and other scientists to ensure a smooth and productive flow of data and models to develop policy-relevant ground water value estimates.

Ground Water Functions

The linkages between biophysical changes in ground water quantity or quality (Box 7), changes in ground water services (Box 8) and changes in economic values (Box 9) can be better understood by considering ground water functions. Typically for shallow aquifers, the biophysical dimensions of ground water quantity and quality determine two broad functions.

The first function is storage of a water reserve or stock (Table 1). Ground water stored in an aquifer provides a reserve of water with given quantity and quality dimensions. The quantity dimension includes the amount of ground water available within a specific geographic region in a given time period, and the change in this quantity over time from recharge and extraction. Rates of natural recharge, natural discharge, and human-induced extraction must be considered. Quality includes both natural and human induced contaminants that may affect the services to which ground water can be applied in a given time period, and the change in quality over time due to natural processes. The rates of human-induced contamination and natural sources of contamination must also be considered.

Table 1. FUNCTION: STORAGE OF WATER RESERVE (STOCK). Ground water stored in an aquifer provides a reserve (stock) of water which can be directly used to generate services. Potential service flows and effects of these services are listed below.*

	SERVICES	EFFECTS	VALUATION TECHNIQUES
	Provision of Drinking Water	Change in Welfare from Increase or Decrease in Availability of Drinking Water	Market Price/Demand Function Supply or cost Function Producer/Consumer Cost Savings Cotangent Valuation Hedonic Price/Property Value Benefits Transfer
		Change in Human Health or Health Risks	Market Rice/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
2	Provision of Water for Crop Irrigation	Change in Value of Crops or Production costs	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Property Value Benefits Transfer
		Change in Human Health or Health Risks	Market Price/Demand Function Supply or cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
3	Provision of Water for Livestock	Change in Value of Livestock Products or Production Costs	Market Price/Demand Function Supply or cast Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Property Value Benefits Transfer
		Change in Human Health or Health Risks	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer

Table 1 Continued

4	Provision of Water for Food Product Processing	Change in Value of Food Products or Production Costs	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Property Value Benefits Transfer
		Change in Human Health or Health Risks	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
5	Provision of Water for Other Manufacturing Processes	Change in Value of Manufactured Goods or Production Costs	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer
6	Provision of Heated Water for Geothermal Power Plants	Change in Cost of Electricity Generation	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cast Savings Contingent Valuation Benefits Transfer
7	Provision of Cooling Water for Other Power Plants	Change in cost of Electricity Generation	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer
8	Provision Water/Sod Support System for Preventing Land Subsidence	Change in cost of Maintaining Public a Private Property	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer
9	Provision on Erosion and Flood Control through Absorption of Surface Water Run-Off	Change in Coat of Maintaining Public or Private Property	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer
10	Provision of Medium for Wastes and Other By-Products of Human Economic Activity	Change in Human Health or Health Risks Attributable to Change in Ground water Quality	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
		Change in Animal Health or Health Risks Attributable to Change in Ground water Quality	Market Price/Damand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Averting Behavior Benefits Transfer
		Change in Economic Output Attributable to Use of Ground water Resource as "Sink" for Wastes	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer

Table 1 Continued

11	Provision of Clean Water through Support of Living Organisms	Change in Human Health or Health Risks Attributable to Change in Water Quality	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
		Change in Animal Health or Health Risks Attributable to Change in Water Quality	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Averting Behavior Benefits Transfer
		Change in Value of Economic Output or Productions Costs Attributable to Change in Water Quality	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer
12	Provision of Passive or Non-Use Services (e.g.. Existence or Bequest Motivations)	Change in Personal Utility	Contingent Valuation Benefits Transfer

The second function is discharge to surface water (streams, lakes, and wetlands) (Table 2). In the Eastern U.S., for example, the base flow of many streams and rivers is supported by ground water discharge. Through discharge to surface water, ground water indirectly contributes to the services generated by surface waters and wetland ecosystems. Once again there are quantity and quality dimensions in terms of rates of discharge to surface waters and the quality of the discharge supply. It should also be noted that surface water may recharge ground water. In this case, a portion of the services provided under the water reserve or stock function should be attributed to surface water. To simplify exposition we focus on the flow of water from ground water to surface water. Similar logic can be applied to develop values for the effects of surface water flows to ground water.

To quantify the share of surface water services that can be legitimately credited to ground water is a scientific and technical challenge. The primary approach is to model the physical interactions between ground water and surface water services such that the incremental contributions of ground water discharge to surface water can be identified and measured. This task is necessary to avoid double-counting of service flows and, in turn, economic values (e.g., attributing the same service and associated value to both ground water and surface water). For example, assume an aquifer provides a major source of recharge water for a stream which is popular for recreational fishing. Assume also that normal land run-off contributes substantially to the flow of the stream. Suppose two water quality protection policies are implemented during the same time period. One policy is targeted toward improving the quality of aquifer recharge and the other is targeted toward reducing pollutant loads from land run-off. Assume the policies will collectively increase recreational fish catch by 50%. To avoid double counting, the total economic value of this increase in fish catch should be divided between the two policies based on the relative contribution of each policy to the 50% increase in fish catch.

Table 2. FUNCTION: DISCHARGE TO STREAMS/LAKES/WETLANDS. Ground water contributes to the flow or stock of water in streams, laker, and wetlands. A portion of surface water and wetlands services are therefore attributable to the ground water resource. Potential service flows and effects of these services are listed below.*

	SERVICES	EFFECTS	VALUATION TECHNIQUE
1	Provision of Drinking Water through Surface Water Supplies	Change in Welfare from Increase or Decrease in the Availability of Drinking Water (Access Value)	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Property Value Benefits Transfer
		Change in Human Health or Health Risks	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Saving Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
2	Provision Water for Crop Irrigation through Surface Water Supplies	Change in Value of Crop or Production Costs	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Property Value Benefits Transfer
		Change in Human Health or Health Risks	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cast Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
3	Provision of Water for Livestock through Surface Water Supplies	Change in Value of Livestock Products or Production Costs	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost savings Contingent Valuation Hedonic Price/Property Value Benefits Transfer
		Change in Human Health or Health-Risks	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
4	Provision of Water for Food Product Processing through Surface Water Supplies	Change in Value of Food Products or Production Costs	Market Price/Demand Function Supply Cost Function Consumer/Producer Cost Savings Contingent Valuation. Hedonic Price/Property Value Benefits Transfer
		Change in Human Health or Health Risks	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer

Table 2 Continued

5	Provision of Water for Other Manufacturing Processes through Surface Water Supplies	Change in Value of Manufactured Goods or Production Costs	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer
6	Provision of Cooling Water for Power Plants through Surface Water Supplies	Change in Cost of Electricity Generation	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer
7	Provision of Erosion, Flood, and Storm Protection	Change in Cost of Maintaining Public a Private Property	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer
		Change in Human Health or Health Risks through Personal Injury Protection	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
		Change in Economic Output Attributable to Use of Surface Water Supplies for Disposing Wastes	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer
8	Transport and Treatment of Wastes and Other By-Products of Human Economic Activity through Surface Water Supplies	Change in Human Health or Health Risks Attributable to Change in Surface Water Quality	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
		Change in Animal Health or Health Risks Attributable to Change in Surface water Quality	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Averting Behavior Benefits Transfer
		Change in Economic Output Attributable to Use of Surface Water Supplies for Disposing Wastes	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer

Table 2. Continued			
9	Support of Recreational Swimming, Boating, Fishing, Hunting, Trapping and Plant Gathering	Change in Quantity or Quality Recreational Activities	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Travel Cost Method Benefits Transfer
		Change in Human Health or Health Risks	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
10	Support of Commercial Fishing, Hunting, Trapping, Plant Gathering	Change in Value of Commercial Harvest or Costs	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer
11	Support of On-Site Observation or Study of Fish. Wildlife. and Plants for Leisure. Educational or Scientific Purposes	Change in Quantity or Quality of On-Site Observation or Study Activities	Market Price/Demand Function Supply or Cost Functions Consumer/Producer Cost Savings Contingent Valuation Travel Cost Method Benefits Transfer
12	Support of Indirect, Off-Site Fish, Wildlife, and Plant Uses (e.g. viewing wildlife photos)	Change in Quantity or Quality of Indirect, Off-Site Activities	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Travel Cost Method Benefits Transfer
13	Provision of Clean Air through Support of Living Organisms	Change in Human Health or Health Risks Attributable to Change in Air Quality	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
		Change in Animal Health or Health Risk Attributable to Change in Air Quality	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Averting Behavior Benefits Transfer

Table 2. Continued

14	Provision of Clean Water through Support of Living Organisms	Change in Human Health or Health Risks Attributable to Change in Water Quality	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
		Change in Animals Health or Health Risks Attributable to Change in Water Quality	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Averting Behavior Benefits Transfer
		Change in Value of Economic Output or Productions Costs Attributable to Change in Water Quality	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer
15	Regulation of Climate through Support of Plants	Change in Human Health or Health Risks Attributable to Change in Climate	Market Price/Demand Function Supply or cost Function Consumer//Producer Cost Savings Contingent Valuation Hedonic Price/Wage Averting Behavior Benefits Transfer
		Change in Animal Health or Health Risks Attributable to Change in Climate	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Averting Behavior Benefits Transfer
		Change in Value of Economic Output or Production Costs Attributable to Change in Climate	Market Price/Demand Function Supply or Cost Function Consumer/Producer Cost Savings Contingent Valuation Benefits Transfer
16	Provision of Non-Use Services (e.g.. Existence Services Associated with Surface Water Body or Wetlands Environments or Ecosystems Supported by Ground water	Change in Personal Utility or Satisfaction	Contingent Valuation Benefits Transfer

Because of the interrelationships between ground water and surface water, surface water recharge to ground water and vice-versa, the aquifer functions listed in Tables 1 and 2 are not independent. Ground water recharge and discharge are both part of the water reserve or stock function because each affects the quantity and quality of water which exists in an aquifer in a given time period. Ground water recharge and discharge also are both part of the surface-recharge discharge function because both affect the quantity and quality of surface water. Because ground water discharge affects a different set of economic services supported by surface water quantity and quality, we include ground water discharge to surface water as a separate function (primarily for economic benefit accounting purposes). A hydrologist can estimate a water budget for a watershed and its underlying aquifers to establish the principal water flows. From a biophysical or ecologic perspective, however, it should be kept in mind that the two broad functions are highly interrelated. Interrelationships between these two functions need to be accounted for when modeling the linkages between policy changes, changes in ground water quantity or quality, and changes in economic values, as illustrated in Figure 1.

Ground Water Services

As with value, we use the term “service” in a neutral sense to imply that a service is neither inherently good nor bad. Services may have both positive and negative effects, depending upon the affected party's preferences or perspective. Services associated with the water reserve or stock function are listed in Table 1. A major service with this function is the provision of drinking water. In the United States, ground water accounts for about 35 percent of public water supplies and 80% of rural domestic supplies (American Institute of

Professional Geologists. 1985). Overall, ground water supplies drinking water to 53 percent of the C.S. population (this figure includes private wells). Ground water is also extracted for use in irrigated agriculture; many industrial purposes, heated water for geothermal power plants, and cooling water for other power plants.

In some regions of the United States, ground water provides the service of supporting underground water/soil structure which acts to prevent land subsidence. The water storage function also helps to control flooding and erosion by providing a medium for absorbing potential surface water run-off. The underground water/soil structure of an aquifer also provides a medium for the absorption, transport, and dilution of wastes (e.g., sewage) and other by-products of human economic activity. Note that each of these services are jointly provided by soil structure and ground water in a given area. As with the services of the surface water discharge-recharge function, the incremental (marginal) contributions of ground water to these services must be quantified.

An aquifer may also generate non-use or passive use services (Bishop and Welsh, 1992; Freeman, Chap. 5, 1993). For example, these services may be attributable to the mere existence of an aquifer, independent of any current or future use. Alternatively, passive use services of providing potable drinking water to future generations may arise from bequest motivations on the part of the current generation.

Most major services provided by ground water under the water reserve or stock function are also included as indirect services associated with the discharge to surface water function (Table 2). To the extent that ground water supports healthy and abundant surface waters, it also contributes to a variety of services generated by these environments. These services include recreational swimming, boating, fishing, hunting/trapping and plant gathering; commercial fishing, hunting/trapping and plant gathering; and, aesthetics and ecosystem life support. Unless biophysical data are available to identify ground water's marginal contributions to these services, there is a high probability of double counting such that ground water program values may be assigned to surface water programs or vice versa.

Relating Changes in Ground Water Services to Economic Measures

Prior to estimating changes in economic values (Box 9, Figure 1), changes in ground water services must be related to changes in economic activities. Examples of potential effects on economic activities are listed in the second columns of Tables 1 and 2. Under the "stock" function, for example, the potential effects of a change in the provision of drinking water include a change in utility from an increase or decrease in the availability of drinking water (access/quantity) and a change in human health or health risks (quality).

Defining changes in human health or health risks requires careful consideration of such issues as changes in mortality and morbidity, and cancerous and noncancerous health threats. Identification of the various types of health effects which can result from changes in ground water quality requires input from health professions. What is ultimately needed are dose-response models that link contaminant sources to changes in contaminants in ground water and then changes in human health. These dose-response models will facilitate defining the baseline and alternative service flows (S^o and S^1) and the estimation of policy-relevant values. Such linkages are essential for identifying changes in all service flows, not just human health effects.

Measuring Economic Values

Once changes in ground water services are identified and quantified (Box 8, Figure 1). the final step in the benefit estimation process is to assign monetary values to these service changes (Box 9, Figure 1). Complete valuation of a change in the condition of ground water involves measuring the economic values for all relevant changes in ground water services associated with changes in the X and Q vectors. Thus, as suggested in the previous section, extensive knowledge of the ground water resource itself and its functions are crucial to defining the change in service flows, and the effects on economic activities of these changes in service flows.

A number of empirical techniques are available for estimating changes in economic value associated with changes in ground water services. We do not attempt to define and explain each potential valuation technique in detail in this paper. An overview of valuation techniques relevant to ground water quantity and quality is provided in Appendix A of the "Guidelines for Performing Regulatory Impact Analysis" (U.S. EPA, 1983). More detailed descriptions of valuation techniques for environmental policies, including advantages and disadvantages of the various techniques, can be found in a number of references (e.g., Braden and Kolstad, 1991; Freeman, 1993). We list potential valuation techniques for changes in ground water services in the last column of Tables 1 and 2.

Selection of a valuation technique for a particular policy application involves many considerations (e.g., theoretical consistency, data availability, estimation robustness, time constraints, budget constraints, acceptable accuracy and reliability). These criteria are sometimes conflicting so that one measurement approach will not be the most prefered in all situations. Rather. the final selection is likely to involve a "balancing" of all relevant considerations.

Aggregation. Intergenerational and Uncertainty Issues

Once the economic value of ground water to an individual is determined, aggregate economic value is estimated by summing individual economic values (e.g., mean willingness-to-pays) over the total number of people in the "market area" and summing these values over time (Freeman, Chap. 7, 1993). For a given aquifer, there are likely to be different market areas associated with each of the services listed in Table 1. Determining the scope of these market areas is a complex process, involving careful study of the spatial distribution of consumers and producers who benefit from the services of ground water from a specific aquifer.

There is not, however, a clear consensus in the literature on how to determine market size. Nearly all environmental economists agree that the market should include all individuals who are affected by a change in the condition of. ground water resource. However, this agreement breaks down when discussions move to who specifically is affected. Physical data are often missing to develop direct links (e.g., dose-response functions) between changes in ground water and the economic activities of potentially affected populations. This problem is exacerbated for nonuse values (generated by bequest or stewardship motivations, for example, which affect people's welfare but are not derived from an economic activity that can be observed.

Methods of summing values over time are also controversial. Ground water policies result in changes in the flow of ground water services over some time horizon (e.g., 50 years). The economic value of the policy in each time period (t) is the difference in the value of ground water quantity and quality with the policy in that time period (X_t^1, Q_t^1) and the value of what ground water quantity and quality would have been without the policy (X_t^0, Q_t^0). That is,

$$\Delta S_t = S_t^1(X_t^1, Q_t^1) - S_t^0(X_t^0, Q_t^0).$$

The total economic value of the ground water resource to the current generation is the discounted sum of the values in each time period (ΔS_t) over the planning horizon (T). The controversy is over the choice of discount rate. The process of discounting benefits to calculate present values automatically, downweights future benefits. Assuming the same monetized value of aggregate benefits in each time period, discounting results in an ever decreasing present value of benefits in each successive time period. After a certain point in the future (e.g. 50 years), the discounting process renders the present value of future benefits trivial. Thus, it is sometimes argued that the process of discounting or downweighting future benefits to calculate present values is "unfair" to future generations. Moreover, the benefits, costs and discount rate used in any analysis are solely representative of the preferences of the current generation.

Intergenerational equity or fairness concerns have resulted in debates over how best to (or not to) discount-future benefits. These concerns have often focused discussion on the choice of a discount rate to use in calculations of net present values. Individuals and groups who desire to see more weight placed on future benefits, for example because of concern over the well-being of unborn generations, argue for lower discount rates. Individuals and groups who are more worried about the negative effects on the current economy of reducing current private consumption and on capital accumulation, which would also benefit future generations, argue for higher discount rates (Sassone and Schaffer, Chap. 6, 1978).

The discount rate used in ground water policy analysis, or the analysis of any public program, is based on societies' marginal time preference for consumption. Since this concept is difficult to quantify, we believe the choice of a discount rate is fundamentally a normative decision. In the case of environmental policy analyses, this decision has been made by some branch or office of the federal government (Office of Management and Budget, 1992). That is, the discount rate which should be used to discount future ground water benefits (which reflects some subjective assessment of the preferences of future generations and weighting of their well-being) is "handed down" to policy analysts[1]. Although ground water policy analysts may be required to use a certain discount rate, the present value of future ground water benefits can be calculated using a variety of discount rates to assess the sensitivity of present-value calculations to the choice of a discount rate. Sensitivity analyses should not be used to identify a desired outcome, but to examine the effects of a number of plausible discount rates.

Because data regarding the quantity and quality of ground water are imperfect, the actual changes in ground water services may be uncertain with associated probabilities of occurrence. This uncertainty may exist with respect to both the current level of services (S^0) projected into the future and the alternative level of services (S^1). Thus, the changes in service flows are modeled as expected rather than deterministic. The expected changes in

[1] Benefit estimates are based on the preferences of the current generation and the choice of a discount rate is based on the preferences of the current generation. Benefit-cost analyses, therefore, contain the implicit assumption that preferences do not change over time. Special concern for future generations only enter if nonuse values, based on bequest motivations perhaps, are included in the benefit assessment

ground water service flows are a function of possible alternative changes in the baseline and future ground water conditions, and the probabilities of each one of these alternatives occurring. In some situations, there may be a number of possible alternative service flow changes, each having a different probability of occurring. In other situations, there may be only one service flow of interest with several competing policies for accomplishing the goal and each policy has a different probability of success. Freeman (1993:Ch. 8) demonstrates how measures of economic value must be adjusted to reflect uncertainty.

Concerns over the effects of current policy decisions on future generations intensify when suspected irreversibilities are present. For example, suppose a particular aquifer is threatened by contamination, remediation of the aquifer would be extremely costly and natural bioremediation may take decades or longer. Also, suppose that the aquifer is not currently a significant source of water for human use. However, there is a chance, because of population growth, that the aquifer may become a major source of water for humans in the future. The uncertainty of future population growth combined with the discounting process may result in very low weights being placed on the possible future benefits of protecting the aquifer from contamination. Consequently, a policy to protect the aquifer from contamination may not pass a standard benefit-cost test.

Whether or not these costs should be borne by future generations is largely a normative issue. The flip-side of the issue is that protecting the aquifer from contamination may impose major costs on the current generation. Paying these costs may reduce the well-being of the present generation, and could end up having little or no effect on future generations if future demand for water from the protected aquifer never materializes.

When uncertainty and irreversibility are major issues and benefits to future generations are of concern, the costs to the present generation of protecting ground water should be considered but may not comprise the definitive decision criteria. Although the economics of a safe minimum standard (Bishop, 1993) for resource protection are not clear (Ready and Bishop, 1991). decision makers may still want to consider protecting selected ground water resources if the costs to the present generation are not unreasonably high. In such cases, ground water managers may want to develop several policy scenarios for protecting ground water resources and then investigate the cost effectiveness of accomplishing the protection programs. The question remains whether the protection costs are unreasonably high since benefits no longer play a central role. This again is a normative decision which must eventually be made at some administrative level.

III. APPLICATION OF GROUND WATER VALUES TO POLICY DECISIONS

Assessment of ground water policies should consider the full range of benefits of the policy including those which can be quantified monetarily, and those which cannot be quantified monetarily.[2] In this section, we discuss a general process or protocol for assessing the benefits of ground water policies. The overall goal of the protocol is to generate and apply economic value estimates consistently across ground water policy decisions. In addition, following the protocol may help to avoid duplication of efforts and potential double-counting of values. The protocol could also provide a framework for

[2] Although our focus is on potential benefits, the discussion also provides insight on potential costs of a proposed regulation since social costs are often foregone benefits (or opportunity costs).

building an economic value database. Such a database could include concise summaries of previous valuation efforts so that future valuation efforts could build upon the existing knowledge base.

Protocol Components

The first component of our protocol is for the policy analyst to record answers to the following questions that relate to Boxes 1-7 in Figure 1 and comprise the technical data necessary for estimation of benefits, Boxes 8-9. Specifically,

1. What is the proposed action?
2. What is the curent ground water condition? If it is contaminated, what are the contaminants, their concentration levels, and their geographic extent? What are the potential contaminants and their expected concentrations and geographic extent? What quantity of ground water is covered by the proposed action?
3. What are the sources of contamination or quantity changes that the proposed action addresses?
4. How are the quantity and quality of ground water expected to change over time in the absence of this action (reference condition)? How are the quality and quantity of ground water expected to change over time with this action (subsequent condition)?

The next component of the protocol is to identify affected services that give rise to benefit estimates. This issue relates to both the stock and ground water discharge functions (Tables 1 and 2). Assessment of potential changes in services can be facilitated by completing matrices such as those shown in Tables 3 and 4. These tables are partially filled out for a hypothetical policy. The first step in completing the tables is to assess the reference condition for the services listed under each function in Tables 1 and 2. For example, affected services for the stock function are documented in Table 3. The “Reference Conditions" indicate that the aquifer provides an adequate supply of drinking water through public or private wells and is uncontaminated. These quantity and quality dimensions are known with certainty. The aquifer is not directly utilized for crop irrigation, livestock watering, or food processing services, as indicated by the "no" entries in the second column of Table 3. To clarify interpretation of the table all other entries for these services are left blank. Thus, the body of the table only documents affected services. Completing the first column indicates that a service was considered and purposely excluded. The information in the first column also briefly notes why a potential service is excluded.

The entries for the discharge function in Table 4 indicate that the aquifer indirectly provides water for crop irrigation and livestock watering, but surface water is not used for human consumption. Again, quantity is assumed to be adequate, but the quality is threatened by contaminant sources of ground water. The extent and timing of the potential contamination is unknown.

A starting point for assigning monetary values to changes in ground water services is an assessment of available valuation data. See Boyle (1994). Available value estimates would be graded as to their suitability for transfer to the current ground water valuation issue. For discussions of criteria for selecting value estimates see the special issue of Water Resources Research (Vol. 28, No. 3, 1992) dealing with benefits transfer. We ‘do not envision this process as being purely qualitative (e.g., good, average or poor), but dealing with specific issues of how the available value estimates relate to the policy situation being evaluated. For example, are the same contaminants involved? Are the magnitudes of contamination comparable? Were the valuation studies conducted adequately, e.g., are estimates biased or have large variances?

Table 3. Changes in Ground Water Service - Stock Function

Service	Reference Conditions					Subsequent Conditions						
	Affected by proposed Rule (If no, why?)	Quantity	Quality		Uncertainty	Quantity			Quality			Uncertainly
			Contam-ination	Concen-tration		Increase	Decrease	No Change	Increase	Decrease	No Change	
Drinking Water	Yes	Adequate for Current Demand	None	N/A	None			x		Potential Decrease		Extent and timing of contam-ination
Crop Irrigation	No (No known or antici-pated use)											
Livestock Watering	No (No known or antici-pated use)											
Food Product Processing	No (No known or antici-pated use)											
etc.												

Table 4. Changes in Ground Water Services - Discharge Function

Service	Reference Conditions					Subsequent Conditions						
	Affected by proposed Rule (If no, why?)	Quantity	Quality		Uncertainty	Quantity			Quality			Uncertainty
			Contam-ination	Concent-ration		Increase	Decrease	No Change	Increase	Decrease	No Change	
Drinking Water	No (No known or antici-pated use)											
Crop Irrigation	Yes	Adequate for current demand	None	N/A	None			X		Potential Decrease		Extent and timing of contam ination
Livestock Watering	Yes	Adequate for current demand	None	N/A	None			X		Potential Decrease		Extent and timing of contam ination
Food Product Processing	No											
etc.												

As an example. suppose there is a potential decrease in the quality of drinking water provided directly by the aquifer. This change is represented by an increase in the concentration of Chemical Z of 30 ppb. As indicated in Table 5a, the proposed policy will not affect the quantity of ground water available for human consumption, and the aquifer is not directly used for the other services listed in Table 3. The "Increment Evaluated" under "Quantity Changes" is listed as "no effect" in Table 5a. The value columns for the quantity change, therefore, are left blank to facilitate interpretation of the table. The increment of contamination to be evaluated is documented under the "Quality Changes" heading in Table 5a. We assume that the water can be made safe for drinking, but expenditures must be made on water purification. For our hypothetical example we assume value data are not available to assign initial values to the reduction in **quality.**[3]

After assessing available data, additional data needs are identified. This covers services for which available value estimates are not appropriate and services for which value estimates do not exist. Continuing with the example, value estimates are only needed for a reduction in water quality for human consumption under the stock function. We identify averting cost as a minimum estimate and contingent valuation as a procedure for estimating the full value the public places on avoiding potential contamination (Table 5b). Values included in contingent valuation estimates, but excluded from averting costs, include disutility from having to invest and maintain treatment systems for private wells and potential nonuse

[3] A number of Meta analyses of environmental values are being developed. We know of only such analysis related to ground water (Boyle et al., 1994). Such Met analyses can be a source of initial value estimates for policy assessments (Smith and Huang, 1993; Smith and Kaoru, 1990; Smith and Osborne, 1993; and Walsh et al., 1988).

values. The question mark in Table 5b for value estimates indicates the values to be estimated. After the study is completed, the question mark would be replaced by the estimate(s). Tables similar to 5a and 5b can be developed for the function of ground water discharge to surface water. We omit this step here for expositional convenience.

Table 5a. Available Data for Valuing Changes in Ground Water Services - Stock Function

Services	Quantity Changes			Quality Changes		
	Increment Evaluated	Value Estimate(s)	Valuation Method	Increment Evaluated	Value Estimate(s)	Valuation Method
Drinking Water	No effect			30 ppb Reduction	None Available	N/A
Crop Irrigation	No effect			No effect		
Livestock Watering	No effect			No effect		
Food Product Processing	No effect			No effect		
Etc.						

The final step is to identify services that will not be monetized and the reasons for these decisions (Table 6). We assume there are no effects that are not monetorized in this simplistic example. We do assume there is a 50% chance of the 30 ppb contamination actually occurring. The expected change can be monetorized in some instances using appropriate measures of economic value under uncertainty (e.g., option price described previously). However, in some cases this will not be possible. In such instances, sensitivity analyses conducted with plausible value estimates can be utilized to consider the effect of the uncertainty on the outcome of the entire benefit-cost or cost-effectiveness analysis. Another source of uncertainty in the current example is the geographical extent of the contamination. It is assumed that this factor is not known and can not be accurately predicted. Thus, several scenarios of damages might be investigated to consider the impact on aggregate value estimates.

Table 5b. Needed Data for Valuing Changes in Ground Water Services - Stock Function						
	Quantity Changes			Quality Changes		
Service	Increment Evaluated	Desired Valuation Method	Value Estimates	Increment Evaluated	Desired Valuation Method	Value Estimates
Drinking Water	No effect			30 ppb Reduction	Contingent valuation or averted cost	?
Crop Irrigation	No effect			No effect		
Livestock Watering	No effect			No effect		
Food Product Processing	No effect			No effect		

Table 6. Other Valuation Considerations for Changes in Ground Water Services - Stock Function			
Services	Nonmonetorized Effects (Reason Why)	Treatment of Uncertainty	Sensitivity Analyses
Drinking Water	None	50% chance of contamination	Geographical extent of contamination
Crop Irrigation	None		
Livestock Watering	None		
Food Product Processing	None		

IV. CONCLUDING COMMENTS

Conducting an economic assessment of ground water policies that adequately consider the full range of effects of a policy is a major undertaking. Because the full range of services of the ground water resource had not been described, the previous values for these services or changes in them may have resulted in an undervaluing of the resource in policy decisions. Benefit estimation can be facilitated by carefully identifying, measuring, and documenting the linkages and “chain of events” shown in Figure 1, using Tables 1 and 2 as guides for tracing specific linkages between policies, changes in ground water services and value estimates. These tables guide identification and quantification of linkages between a proposed policy, changes in services provided by ground water functions, and the effects of service changes on economic activities and values. This information reveals the gainers and losers of a proposed policy, over both time and geographic space. Using Table 3, 4, 5a, 5b and 6 will facilitate clear and concise documentation of policy assessments. This documentation will report service effects valued as well as those dismissed as not relevant. It will also insure all policy assessments considering ground water values begin at the same starting point, consider the same issues and provide uniform reporting. Establishing structure and consistency across policy assessments is important for producing accurate benefit estimates, avoiding double-counting problems, and eliminating duplication of ground water valuation efforts.

We envision these tables as comprising a concise form for reporting all benefit analyses conducted for ground water policies. The list of questions would comprise a cover sheet to identify the policy issue. Each of the tables would then follow to complete the documentation. This reporting framework would provide a systematic way of documenting and reviewing policy assessments. It may also be helpful to document studies used as secondary sources of value data as has been done by Boyle (1994) for ground water contingent-valuation studies.

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